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# THE TERRESTRIAL DEPOSITS OF OWENS VALLEY, CALIFORNIA

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## INTRODUCTION

From September 9 to December 1, 1909, the writer in company with James A. Lane was in the southern half of Owens Valley, California, studying and mapping the general geology in a semi-detailed manner, and gathering data on the terrestrial deposits. The deposits studied particularly lie in the Mt. Whitney Quadrangle of the United States Geological Survey, though work was done in the Olancha Quadrangle, and beyond the limits of both these sheets, as problems demanded. The results of this work are used as a Doctor's thesis in the University of Chicago, this article being one chapter of that thesis.

The purpose of this paper is threefold: (1) to describe the characteristics of the terrestrial deposits of Owens Valley; (2) to discuss the causes and processes involved in their deposition; and (3) to deduce certain criteria whereby materials so deposited may be distinguished from other deposits such as those of lakes and seas, even after cementation has taken place. The adequate study of such deposits should lead to the establishment of criteria by which terrestrial deposits of earlier ages may with certainty be separated from marine deposits. It should also lead to the establishment of criteria for the recognition of various kinds of non-marine deposits. It is recognized that such criteria have already been discussed, and to a certain extent established. But many of these are applicable only to formations of pronounced characteristics, and there are yet many formations of one age and another whose origins are not yet established beyond doubt.

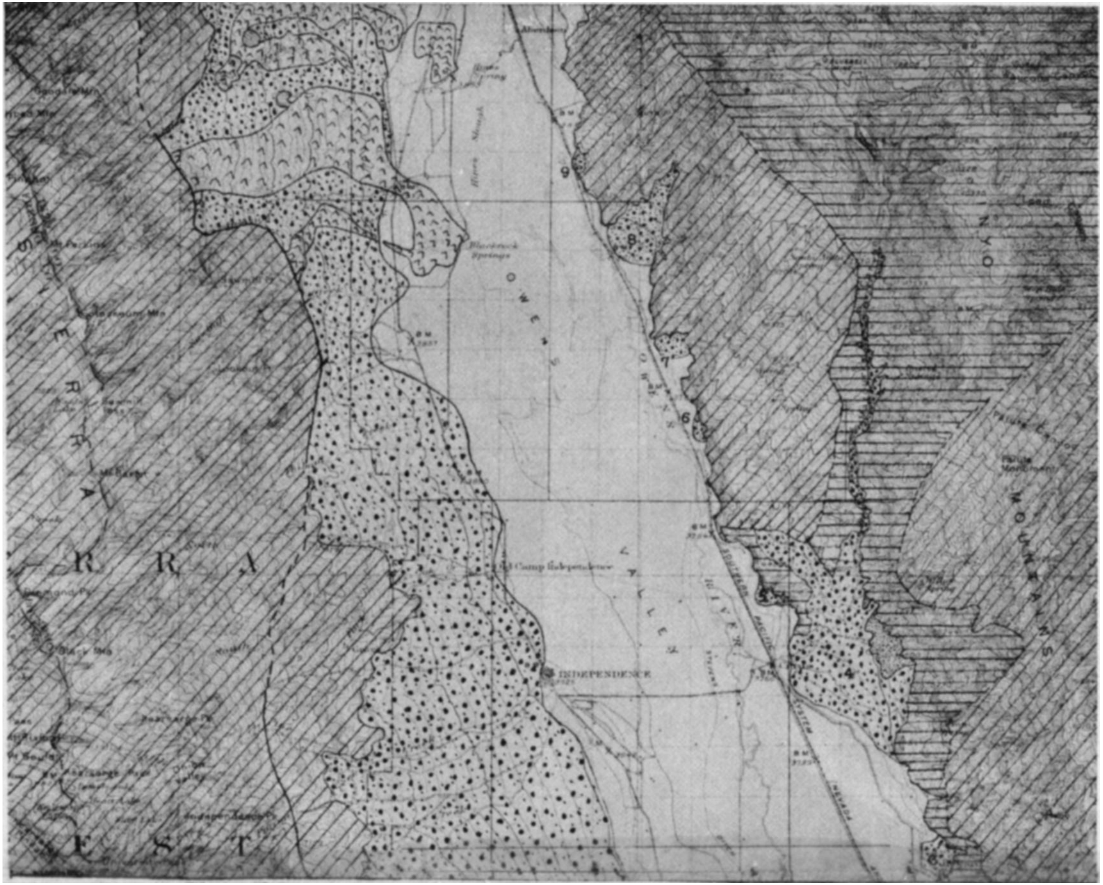
Owens Valley is an area about 100 miles long north and south, by 12–15 miles broad. It is situated in extreme eastern California, about east of a point on the coast midway between San Francisco and Los Angeles. The valley includes the villages of Bishop, Big Pine, Independence, Long Pine, and Keeler, which can be reached by the California and Nevada Narrow Gauge Railroad, connecting with the Southern Pacific at Mina, Nevada.

Physiographically, Owens Valley is located between the Great Basin on the east and the Sierra Nevada Mountain province on the west. The east wall of the valley is the west face of the Inyo Mountains, one of the semi-arid basin ranges, while the west valley wall is the steep eastern slope of the Sierras. Owens Valley, between these two ranges, is occupied partially by Owens Lake, and drained by Owens River which flows into the north end of the lake. The surface of the valley is broken in several places by the Alabama Hills, Poverty Hills, and a series of recent volcanic cones and lava flows (see Plate I).

The eastern face of the Sierra Nevada Mountains is a precipitous fault scarp, probably of late Miocene age, attaining a height of 10,000 ft. above the bottom of Owens Valley. In this slope, streams and valley glaciers have carved numerous deep canyons, whose lower portions are choked with drift and whose upper portions are the cirques and bare surfaces of glacially eroded regions. The rock of the mountains in this region is massive, coarse-grained igneous rock, chiefly granite. This rock is weathered chiefly by mechanical processes. Temperature changes and the wedge work of ice cause pieces of rock varying in size from a fraction of an inch to a score or more of feet in diameter to break off and roll down the steep slopes, each piece being broken or worn smaller as it goes. Plants, animals, and ground water are relatively unimportant as weathering agents here, because by reason of the steep slopes, they are not present in abundance. On the other hand, because of these steep slopes, gravity is more than usually important. Oxidation, hydration, carbonation, solution, etc., as usually performed by atmosphere and ground water, do not take place sufficiently rapidly to produce great results on the rocks before these last are disrupted and taken away. That is, the mechanical processes of weathering and transportation take place more rapidly than the chemical processes, and the result is arkose material carried down the mountain canyons and deposited in the valley below. These are the materials to be described as the terrestrial deposits of the valley.

Unlike the Sierras, the Inyo Mountains contain both igneous and sedimentary rock, in about equal abundance. Ordovician, Carboniferous, and Triassic sedimentary formations have been interbedded with Triassic lavas, and intruded by Cretaceous granite and diorite. Though these mountains are not so high by 4,000 ft. as the Sierras, and the slopes are not so steep, still here also mechanical processes of weathering keep ahead of chemical

Plate I


SIERRA
NEVADA
OWENS VALLEY
OWENS
RIVER
INYO
MOUNTAINS
INDEPENDENCE
Camp Independence
Blackrock Springs
SOUTHERN PACIFIC SYSTEM
NEVADA
4
5
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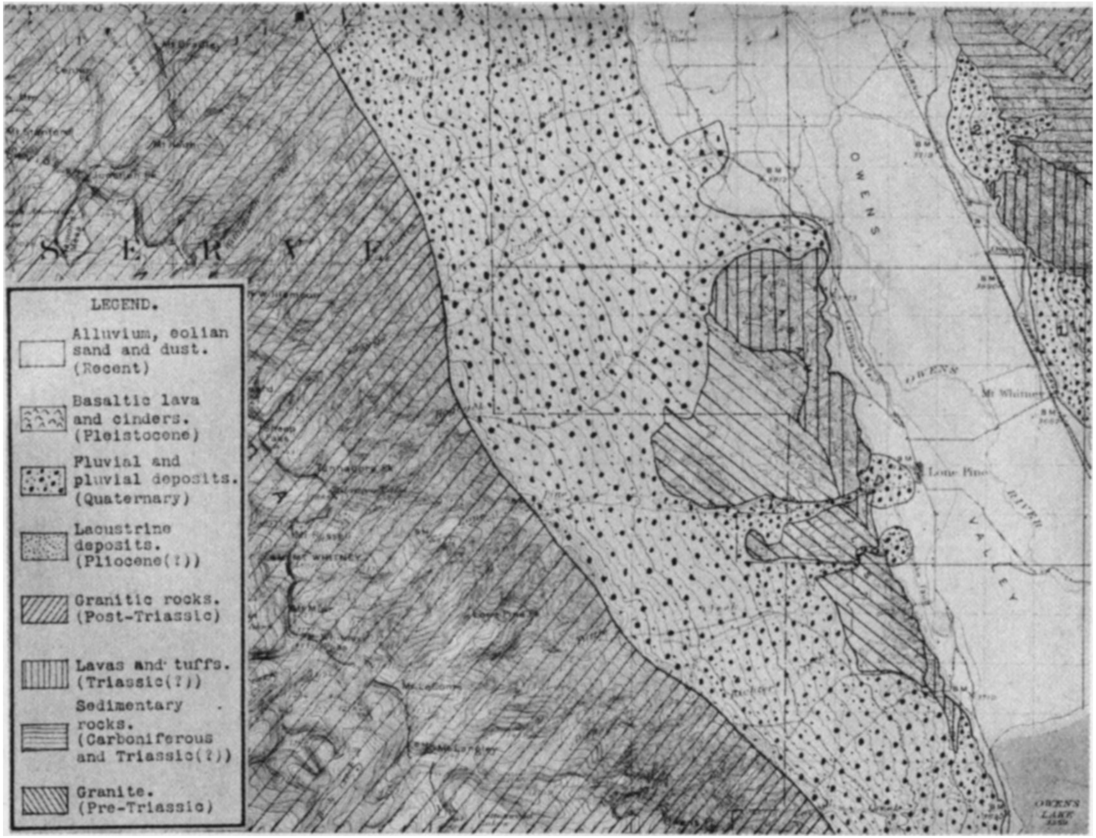
S I E R R A
N E V
LEGEND.
Alluvium, eolian sand and dust. (Recent)
Basaltic lava and cinders. (Pleistocene)
Fluvial and pluvial deposits. (Quaternary)
Lacustrine deposits. (Pliocene(?))
Granitic rocks. (Post-Triassic)
Lavas and tuffs. (Triassic(?))
Sedimentary rocks. (Carboniferous and Triassic(?))
Granite. (Pre-Triassic)
OWENS
OWENS RIVER VALLEY
Mt Whitney
Lone Pine
OWENS LAKE

From Mt. Whitney, Cal., Quadrangle

Scale, about three miles to the inch. Contour interval, 100 feet processes, this being due partly at least to the fact that the Inyo Mountains receive little precipitation, and the moisture necessary for chemical processes is lacking. Here also canyons have been cut by streams, and material has been transported to the valley and deposited, but unlike those of the Sierras these streams are intermittent, and carry material only after the infrequent rains. The Inyo Mountains have not been glaciated.

The deposits considered in this paper occur along the east foot of the Sierra Mountains on the west side of the valley, and discontinuously along the west front of the Inyo Mountains, which border the valley on the east. The phenomena on the opposite sides of the valley are sufficiently unlike to warrant description separately.

## DEPOSITS AT THE BASE OF THE SIERRA MOUNTAINS

### LOCATION AND EXTENT

Within the area of the Mt. Whitney Quadrangle, terrestrial deposits at the east base of the Sierra Nevada Mountains cover a belt 1–7 miles wide. In the Olancha Quadrangle to the south, corresponding deposits extend for many miles in a narrow and more or less disconnected belt.

At the north, the plain of the terrestrial deposits is overlain by recent lavas and volcanic cones. Northwest of Owens Lake the alluvial deposits lie against the west edge of the Alabama Hills, and extend around the north and south ends. Two narrow continuations of the deposit extend through gaps in these hills, and deploy slightly on the east side. Elsewhere the plain joins the flat bottom of Owens Valley along a more or less distinct line. On the west side the plain is limited sharply by the foot of the mountains.

In the aggregate, the deposits cover about 175 square miles in the Mt. Whitney and Olancha quadrangles.

### TOPOGRAPHY

#### FANS AND INTER-FAN AREAS

Topographically, this plain of pluvial and fluvial deposits takes the form of a series of fans joined together at their lateral edges. At first glance, either in the field or upon the topographic maps, it seems to be a continuous plain sloping from the mountains; but studied in detail, it resolves itself into low, gently sloping fans separated by broad, ill-defined, shallow depressions. The fans deploy and become less distinct at a distance from the mountains; the depressions are therefore broader, deeper, and better defined close to the mountains. At its outer edge, the topography of the deposits approaches a plain, in which neither fans nor inter-fan areas can be distinguished.

The axes of the fans are on lines which are continuations of canyons in the mountains; the depressions are between the mouths of the canyons.

From Owens Lake north, the following fans can be distinguished: those of Richter, Tuttle, Lone Pine, Hogback, George, Bairs, Shepard, Pinyon-Pine, Oak, Thibaut, and Sawmill creeks. The last three are small though sharply defined.

A few notes taken north of Lone Pine Creek are here copied, in so far as they refer to the topography of the fans:

> The fan opposite Lone Pine Canyon is sharply set off from the fan of Hogback Creek to the north. Beginning at the mouth of the canyon, it spreads promptly to the north, a distance of about half a mile at the immediate foot of the mountains, and one and one-half miles within a distance of a mile from the mountains. Farther from the mountains, it joins the fans on either side, and its distinctness is there lost. Its north edge is fairly distinct for two miles from the mountains, being markedly higher than the broad, irregular, linear depression between it and the fan of Hogback Creek. This depression is distinct near the mountains, but becomes gradually shallower and narrower away from the mountains, until the two fans coalesce two miles or so out. . . . . From the depression, the slope of the fan of Hogback Creek shows a distinct rise. . . . . The south side of the fan of Shepard Creek is not especially well developed, though it is set off distinctly from the fan to the south. The depression between these two fans is about 200 ft. below their tops, and is one-fourth to one-half a mile broad. . . . . North of the fan of Shepard Creek, the surface declines and does not again reach the high level of this fan as far as the alluvium can be seen.

The streams have a distinct tendency to leave their fans for the depressions between. Shepard Creek now flows in the depression south of its fan. The North Fork and South Fork of Oak Creek have joined in the depression between their respective fans. At some time they were undoubtedly parallel streams. The photograph (Fig. 1) shows the two fans, South Fork flowing in the low place, and North Fork leaving its fan for the depression. This shifting of streams to the inter-fan areas is suggested as a common and efficient process in the tying together of fans, making piedmont alluvial plains, or *bajadas*.[1] By this shifting, fans are made between fans, tying them together and tending toward the union of the fans into one plain.

### CHANNELS AND RIDGES

Low ridges and shallow depressions on the individual fans constitute topographic features of a second order. These are the channels and depositional features of the streams which deposited the fans. The depressions are more noticeable than the ridges.

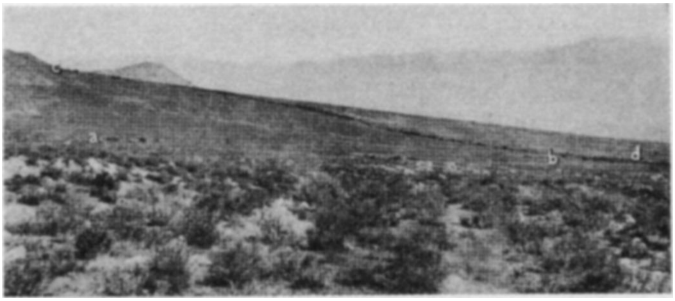

FIG. 1.—A photograph of the fans of Oak Creek, showing South Fork (*ab*) flowing in the inter-fan depression, and North Fork (*cd*) leaving the fan to join South Fork in the depression.

The depressions are, as a rule, about 10 ft. deep and less than 100 ft. across, though at a maximum they reach a depth of 20–25 ft. and a width of quite 100 ft. Their bottoms are usually flat and their slopes as steep as the material will permit. The elevations are less numerous than the depressions, and have less relief. They are seldom more than 5 ft. above the surrounding plain, and their height in many cases is only equal to the diameter of the individual bowlders of which the ridges are composed. The ridges consist of mere divides between channels and of lines of bowlders bordering the channels.

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[1] The term *bajada* has been suggested by C. F. Tolman (*Jour. Geol.*, XVII [1909], 141) to replace the longer term commonly in use. It has the advantage of brevity, but lacks the explanatory value of the older term.

In keeping with their origin, the depressions and ridges are radiate in their arrangement. At the head of each fan, these features are few; toward the outer edge they are numerous; but at the extreme edge they are again rare. Three miles from the edge there are probably 50 channels, for one close to the head, and something like that proportion between the same three miles from the edge and the outer edge itself. Channels which, near the head of the fan, are close together, diverge outward, and each may break up into other channels, each less deep and less broad than the one from which it springs. Quite commonly these channels lead to depressions between fans and disappear.

It is clear that these channels on the fans mark the courses of the distributaries from the fan-making streams. The streams branched again and again, some of the distributaries reaching the inter-fan depressions and flowing off through them. It is equally clear that some of the elevations are merely inter-distributary divides. The origin of the ridges bordering the depressions is not so clear. Possibly they are in principle natural levees, built as the waters overflowed their channels. It is understood that these are the streams which deposited last on the surface of the fans. In the building of the bajada, the channels undoubtedly shifted frequently, those of one time being filled up and a new set formed during periods of greater deposition following heavy rains or the rapid melting of snow in the mountains.

### THE STREAM CANYONS

The streams of the bajada do not now distribute over the fans, but flow in deep, steep-sided, canyon-like valleys; that is, the bajada is being dissected (Fig. 2). This is true to a greater or less extent of all the streams which have played a part in the deposition of the plain.

The canyons in the bajada vary in depth from 20 ft. to 250 ft., and average about 200 ft. in width. The depth is determined by the size of the stream, the height of the fan, and the position of the stream on the fan. The most pronounced canyons are those of

Carroll and Lone Pine creeks, which are large streams flowing in the high central part of well-developed fans. Carroll Creek canyon is 250 ft. deep at the head of the fan, and shallows to less than 50 ft. at the edge of the bajada. Shepard Creek is almost as large as either of the two streams previously mentioned, but it flows on the side of its fan, where the surface and gradient are lower, and its canyon is only 30 ft. deep. Hogback Creek has cut deeply at the head of its fan, but farther out, where the stream has shifted to the side, there is little intrenchment.

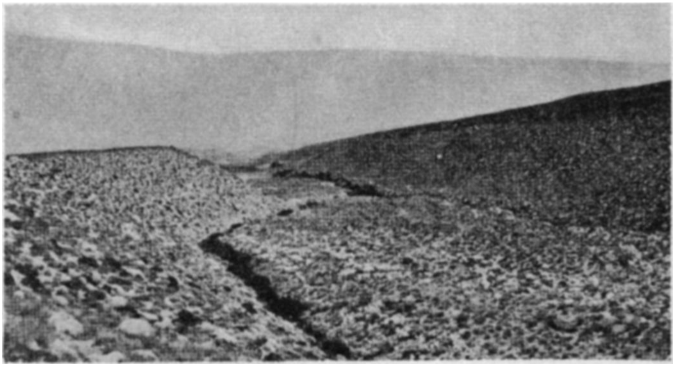

FIG. 2.—The canyon of Carroll Creek in the Sierra bajada. The dark strip consists of trees 20 ft. high.

These canyons are the most conspicuous topographic features of the bajada. They clearly follow the building of the bajada, and were excavated under different conditions. They therefore have both an expository and a historical value. Problems connected with them will be discussed later.

### BOWLDER BELTS

A fourth topographic feature of the bajada consists of almost innumerable lines of bowlders which, though primarily a matter of the constitution of the bajada, affect the topography in a minor way.

These lines of bowlders have a radiate arrangement similar to that of the channels and ridges. The bowlders are so close together as to make low and discontinuous ridges, which by winding his way among the bowlders one may in some instances be able to cross without climbing. The height of the ridges is determined by the size of the bowlders, and is usually less than 10 ft. They seldom consist of more than two thicknesses of bowlders.

### THE SLOPE OF THE BAJADA

The slope of the piedmont plain away from the mountains varies rather uniformly with distance from the mountains. It also varies irregularly from place to place along the foot of the mountains. Along Carroll Creek the slope at the face of the mountain is 18° and 20° (Figs. 3 and 4). Where it is 20°, the angle decreases to about 12° a quarter of a mile from the mountains; and where it is 18° at the mountains, the slope is 6–8° a mile or so out. The fan of Lone Pine Creek has a slope of 6° at the mountains, which decreases almost uniformly to a very low slope at the west edge of the Alabama Hills. The difference between the slopes of the fans of Lone Pine Creek and Carroll Creek might be due to a diastrophic tilting, which either did not occur at Lone Pine Creek or did not

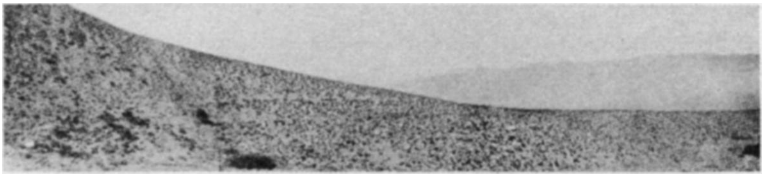

FIG. 3.—The slope of the Sierra bajada as seen on the north wall of the canyon of Carroll Creek.

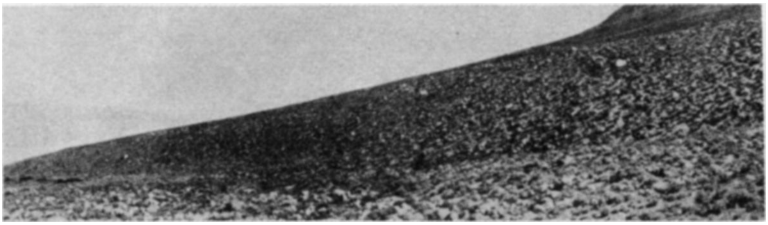

FIG. 4.—The slope of the Sierra bajada on the south wall of the canyon of Carroll Creek.

affect the fan there. However, no other evidence of diastrophism appears at Carroll Creek. Probably the difference is due to variations in the gradient and size of the two streams in the mountain canyons, at the time the fans were built. The *average* slope of the fans in the valley at the base of the mountains is about that of the fan of Lone Pine Creek, 6°. The slope is greater along the axes of the fans than in the inter-fan depressions.

## MATERIALS

The material of the Sierra bajada is not well exposed, but some idea of its upper portion can be obtained. Nothing is known of that portion lower than 300 ft. from the surface, as there are no cuts so deep, and well-records are lacking. The material may be seen in three sets of places: (1) on the unaltered surface of the plain, (2) on the sides of the shallow channels, and (3) in the walls of the canyons.

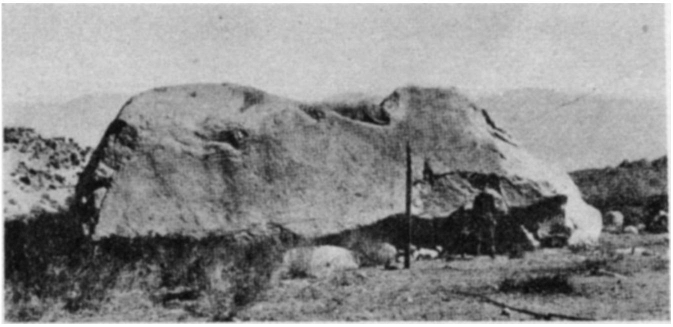

FIG. 5.—The largest bowlder seen in the Sierra bajada. The man is 6 ft. tall. This bowlder lies in the yard of the Cerro Gordo power shanty in Lone Pine Canyon, 1½ miles from the foot of the mountains.

Lithologically, the bajada is composed of material from the granitic rocks of the Sierras, disintegrated rather than decomposed. Its components are bits of granite, rather than crystals of quartz or feldspar. Even the disintegration is not complete, for the material is commonly coarse. It is clear that the source of the material is the mountains, and that it was removed from the parent ledges mechanically, and transported to its present position by streams, aided in the upper parts of the canyons by glaciers. There is every evidence of immature weathering of the materials. At the time the fans were being deposited, the mechanical processes of weathering greatly exceeded the chemical, and transportation was free and rapid.

### TEXTURE

The fans contain all textural grades from pieces the size of small sand grains and even clay particles, to bowlders more than 20 ft. in diameter, but pieces less than an inch in diameter predominate.

The most striking and surprising feature of these fans is the extreme coarseness of *some* of its materials. Innumerable large and small bowlders appear on its surface, on the sides of the shallow channels, and on the walls and floors of the canyons. On the unaltered surface, they occur in radiating lines and belts, roughly parallel with the radiating channels. They are practically confined to the higher parts of the surface, where the main streams flowed. None appears in the inter-fan depressions. More bowlders are scattered near the heads of the fans than toward the outer edges but they are not noticeably larger here. They are arranged in belts or low ridges along the borders of the shallow channels and are scattered more sparsely on the side slopes. Bowlders are numerous on the walls and bottoms of the canyons, but without definite arrangement. The beds of the streams are everywhere choked with them, and they occur in and along the braided channels

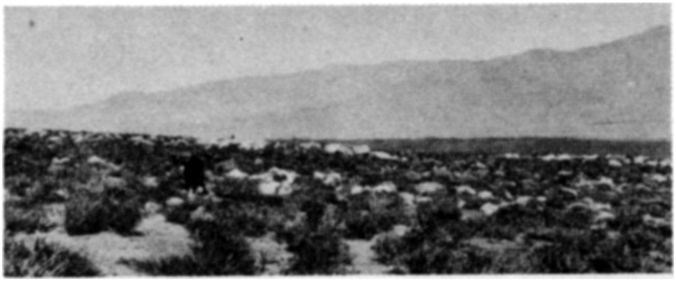

FIG. 6.—Bowlders on the surface of the Sierra bajada. Their size may be estimated from the horse. Picture taken on the fan of Sawmill Creek about a mile from the foot of the mountains.

used by the streams in time of flood. Their unusual abundance in the canyons is doubtless due to the bowlders having been sorted out in the process of canyon-cutting, the finer material being carried on and the coarse left.

The whole surface of the bajada considered, the average diameter of the bowlders is perhaps about 2 ft. but those 8 ft. in diameter are by no means uncommon. The largest seen are a mile west of Lone Pine, 6 miles from the mountains, and at the Cerro Gordo power shanty, on Lone Pine Creek, 1½ miles from the mountains. The one west of Lone Pine is 10×20×30 ft. above ground. The size of the one at the shanty is shown in Fig. 5, the man being 6 ft. tall. With these exceptional bowlders are thousands of others as large as 10 ft. in diameter, as can be seen from Fig. 7. The size and distribution of this coarse material may be seen further in Figs. 6 and 7. Fine material in the bajada is shown in Fig. 8.

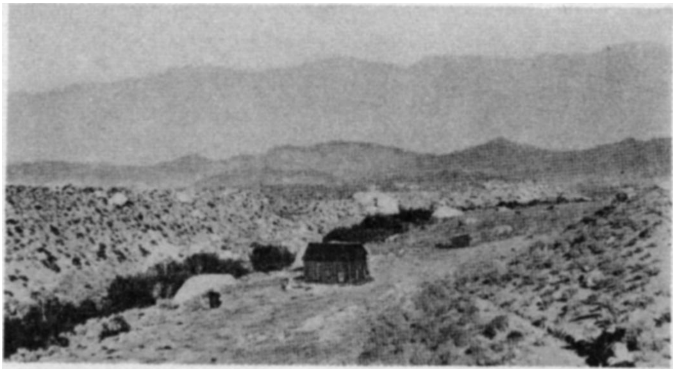

FIG. 7.—The canyon of Lone Pine Creek in the Sierra bajada. Bowlders appear almost as large as the two-story house.

### STRUCTURE

Owing to the scarcity of good exposures, the structure of the materials of the Sierra bajada is not readily determined. The only satisfactory exposure is near the mountains on Lone Pine Creek (Fig. 9). Because the canyon walls never stand in vertical bases, but slump down readily to gentle slopes, they show the texture only, not the structure. The relations of coarse and fine material can be seen to some extent on the surface of the plain.

As has been shown above, the coarse and fine materials are more or less separated on the surface of the plain. There are considerable stretches, usually the lower areas, where the surface material is all fine. Such areas are interrupted by narrow belts of large bowlders. If the structure of the whole plain were judged by its surficial aspect, the material could be known to be roughly sorted into many narrow radiating belts of coarse materials, and broader belts of fine materials. Presumably these lines would not have the same position horizontally for any considerable vertical section, as the stream channels undoubtedly shifted and distributed often.

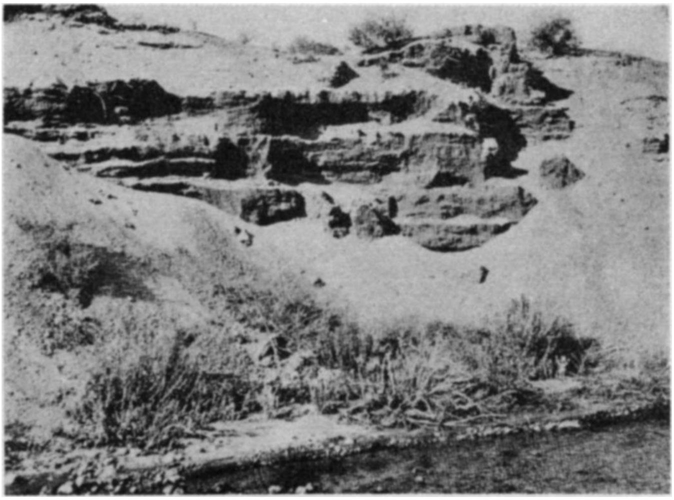

FIG. 8.—Fine material in the Sierra bajada seven miles from the mountains

So far as cuts in the bajada show, the materials consist of a mixture of large blocks of granite, bowlders not so large, angular fragments the size of cobbles, tiny angular bits of rock, sand, and clay. Where any considerable vertical section is seen, these different grades are sorted into indefinite lenses and pockets. There are no definite layers of great extent. Divisions of material are nowhere seen to be continuous for as much as 100 ft. Some small exposures show material which is apparently unstratified. Even where sorted into lenses or irregular areas, there is a considerable mixture of all sorts of material in each division, each merely averaging a little coarser or a little finer than its surroundings.

All materials are clearly water laid, but under conditions which allowed of very poor sorting.

The structure and texture of the materials are brought out best by detailed descriptions and photographs. Such illustrations are given below and in Figs. 9, 10, 11, 12, and 13.

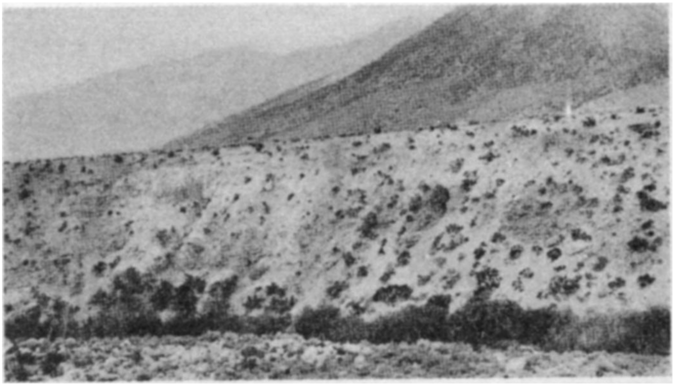

FIG. 9.—A section in the Sierra bajada from the south wall of Lone Pine Canyon, ½ mile west of the Cerro Gordo power shanty.

1. Two hundred to three hundred yards above the power shanty on the south wall of the valley of Lone Pine Creek, wash and gravity have exposed the material almost continuously for a distance of about 100 ft. vertically. The section consists of both fine and coarse material roughly separated from one another. There are two horizons of coarse bowlders, one 20 ft. from the top and the other about 30 ft. from the bottom. In the upper horizon the bowlders are fairly well rounded, and range up to 4 ft. in diameter, the average being about 1 ft. In the lower zone of bowlders there is greater range in size. There are numerous pieces 6 in. through, and several 6 ft. or so in diameter. The sorting is very slight. Between these two horizons the materials are mostly fine, though large bowlders are not entirely absent. Immediately above the

lower zone of bowlders is a fairly well-defined bed of gravel, the constituents of which average 3–4 in. in diameter. Between this gravel layer and the upper zone of bowlders, the material differs in different parts of the cut, the structure being decidedly pockety. In one place the fine gravels grade into the coarse bowlders above; in another, there is a body of clay between the two; in another, the gravel layer does not appear, and clay separates the two beds of bowlders (Fig. 9).

2. A six-foot cut a mile from the mountains shows a matrix of clay and sand in which there are angular fragments averaging 10 in. through, with occasional bowlders 3 ft. in diameter. The bowlders are angular or subangular, and none are well rounded. They are not abundant enough to touch one another. There is apparently no sorting.

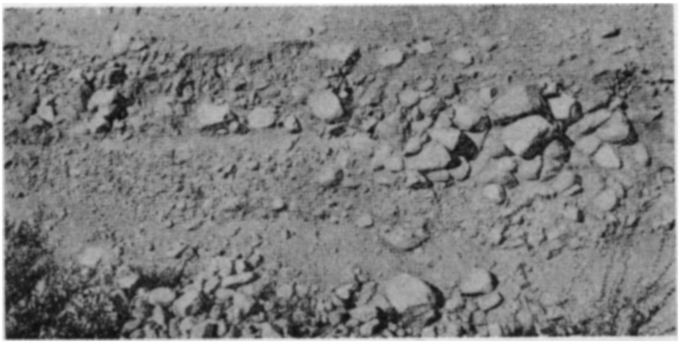

FIG. 10.—Roughly sorted materials of the Sierra bajada on George Creek

3. A hundred yards above the last section, the material is rudely but distinctly sorted. At the bottom there is a fairly uniform layer of angular gravel, averaging 4 ft. in thickness, of which the upper 1½ ft. give place at the east end to a projection downward of a pocket from the coarse layer above. There is little clay in the cut, and the fragments of rock are abundant enough to touch one another. The pores are filled with coarse, arkose sand, loosely packed.

4. The last section gives place, within a few feet, to unsorted material entirely similar to that of section 2. From here to the mountains the sorted and unsorted materials occur with about

equal frequency, in the same position relative to the stream and to the surface of the fan.

5. Material is exposed on the Mt. Whitney trail through the Alabama Hills. It is composed of rounded or partly rounded granitic bowlders, up to a foot in diameter, with a sparse matrix of granitic pebbles. Though stratification is not apparent, all material is clearly water laid (Fig. 12).

6. On Dietz Creek, just above its junction with Tuttle Creek, material is exposed. It is a mixture of very fine angular fragments with material having the texture of coarse sand. The fragments are not so angular as pieces just broken by weathering. They seldom exceed a half-inch in diameter, and the average is about $\frac{1}{16}$ of an inch. The finer material consists of arkose, flakes of mica, grains of pyrite, and of ferro-magnesian minerals, being almost as common as quartz. The coarse and fine materials are unassorted.

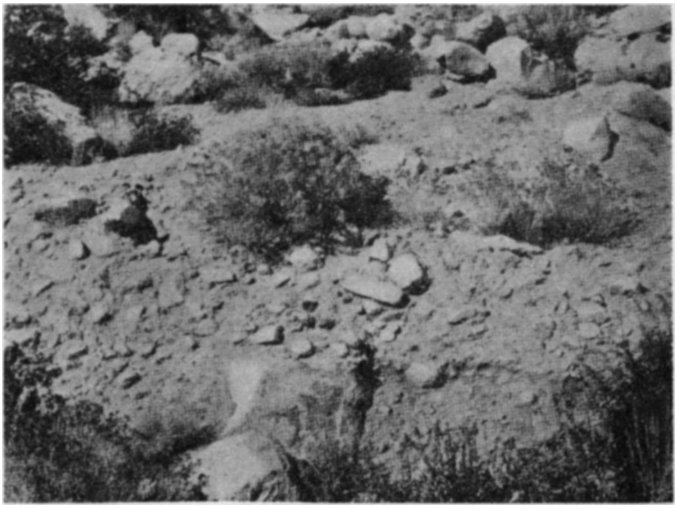

FIG. 11.—Unstratified material on George Creek. This section occurs within only a few feet of that shown in Fig. 10.

From these descriptions and photographs, the following characteristics of the materials are shown:

1. The material was derived from the rock of the Sierra Nevada Mountains.

2. It is the result of immature weathering in the mountains.
3. In texture the materials range from clay-like particles, to bowlders 30 ft. in diameter.
4. Some of the large bowlders are ice-shaped, and some have been shaped slightly by water.
5. Stratified, partly stratified, and entirely unassorted materials occur in something like equal proportions.
6. Where stratification exists, the materials are sorted into lenses and pockets, never into uniform, continuous layers.

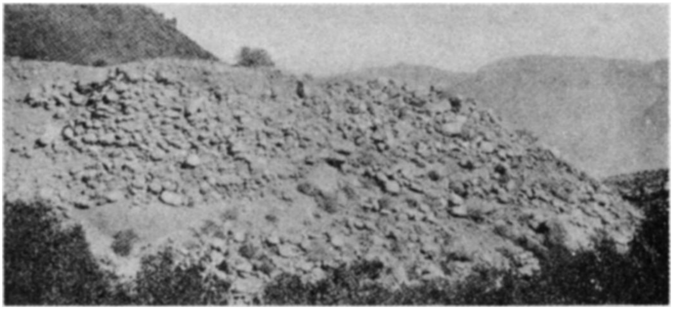

FIG. 12.—A pocket of stratified gravel in the Sierra bajada seven miles from the mountains on Lone Pine Creek.

7. The materials become gradually finer as distance from the mountains becomes greater, at least so far as sub-surface material is concerned.
8. No fossils were found in the material.

These features will be discussed after the deposits at the foot of the Inyo Mountains have been described.

## TERRESTRIAL DEPOSITS OF THE INYO MOUNTAINS

Terrestrial deposits are represented in the Inyo Mountains by two distinct types of materials of two distinct ages. They will therefore be discussed separately.

### PLIOCENE LACUSTRINE DEPOSITS

No description of the terrestrial deposits of Owens Valley, and no discussion of the older deposits at the foot of the Inyo Mountains would be adequate without mention of certain lacustrine clays and sands in Waucobi Canyon, described by Walcott,[1] and in the vicinity of Haiwee described by Turner,[2] Fairbanks,[3] and Campbell,[4] even though such mention leads beyond the confines of the Inyo Mountains. Both these deposits were seen by the writer, and they are here discussed in so far as they may be used as a type of lacustrine deposits. Walcott[5] and Spurr[6] have interpreted these deposits in slightly different ways, but both agree that they are lake deposits, and as such they will be described. Discussion as to whether they record great recent uplift of the Inyo Mountains, as according to Walcott, or were deposited in a deep, widely distributed lake, as Spurr contends, is not in place here, though such discussion is given in the unpublished part of the thesis.

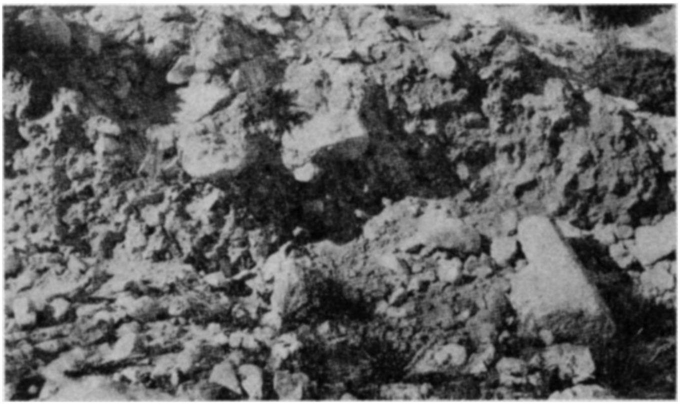

FIG. 13.—Unsorted material of the Sierra bajada

### LAKE BEDS IN WAUCOBI CANYON

Waucobi Canyon, or the Waucobi embayment as it is called by Walcott, is a re-entrant in the west face of the Inyo Mountains a few miles north of the boundary of the Mt. Whitney Quadrangle east of Alvord. In this re-entrant are a series of unconsolidated and partly consolidated sands, clays, and gravels. They were traced from wall to wall of the re-entrant, and up the canyon for some 3½ miles. Mr. Walcott reports their continuation almost to the crest of the mountains.

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[1] C. D. Walcott, *Jour. Geol.*, V, 240–48.

[2] Personal communication to Spurr.

[3] H. W. Fairbanks, *Am. Geol.*, XVII, 69.

[4] M. R. Campbell, *Bull. U.S. Geol. Surv. No. 200*, p. 20.

[5] *Jour. Geol.* V, 344–48.

[6] J. E. Spurr, *Bull. U.S. Geol. Surv. No. 208*, pp. 209–10.

There are two more or less distinct phases of this deposit. Near the north and south walls of the re-entrant are interbedded clays, limestones, and conglomerates. These materials are mostly sorted into distinct beds, but are locally arranged in pockets or irregular areas, when seen in sections. Two miles east by northeast of Alvord, a ledge of limestone and conglomerate outcrops under a low hill of angular alluvium. The limestone is white, porous, earthy, and filled with small fossils of gastropods. Other rock has a matrix of calcium carbonate, but contains enough pebbles to make it conglomeratic, though the pebbles are seldom in contact. The stony matter is fairly well rounded. In size its pieces reach 6 in. in diameter, though the average is about 1 in. The pebbles are mostly of sedimentary rock, but with some granites. All the material is local.

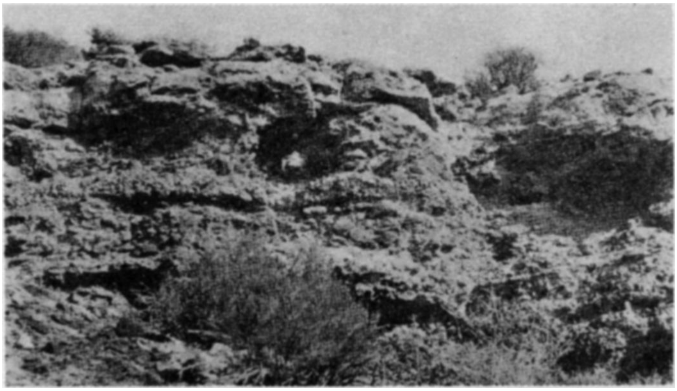

FIG. 14.—Lacustrine limestones and conglomerates, deposited near shore in the Waucobi embayment.

A series of exposures along the main road 1½ miles southeast of the fruit ranch of J. S. Graham, at the southeast margin of the re-entrant, shows well the constitution of the beds. All the material is irregularly sorted. In some places it is of light-yellowish clay, which contains enough lenses and pockets to give it a bedded aspect. In other places it is made up of alternating layers of gravel and clay, the latter containing bowlders in many places (Fig. 14).

Just below these coarse, roughly sorted materials on the main road, the constitution changes abruptly to sandy clay, arranged in continuous, uniform, apparently horizontal layers. The change from coarse, poorly sorted conglomerates to fine clays takes place within 500 ft. These clays appear all the way to the mouth of the canyon, as erosional hills about 100 ft. high, and in the valley walls. Most of the clay is fine, becoming white dust when powdered. Some layers are sandy and some calcareous. They are not usually firmly cemented. Layers 1–10 ft. in thickness can be traced continuously along the hills (Fig. 15).

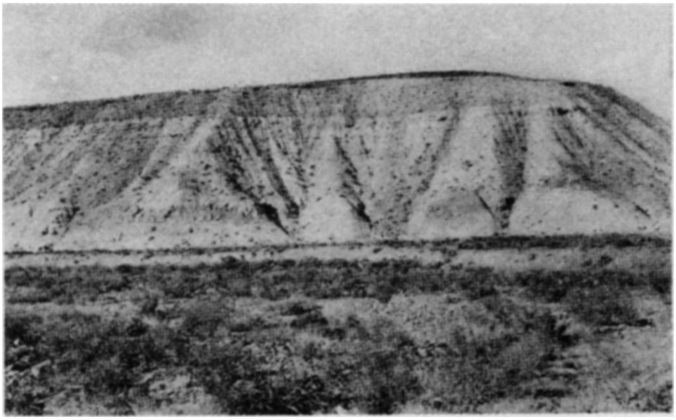

FIG. 15.—Lacustrine sand and clay in the Waucobi embayment. The layers are continuous and of uniform thickness.

These are doubtless lake deposits, the coarser marginal conglomerates being the littoral phase, and the centrally located clays and sands having been deposited in quieter, deeper water, farther from shore. The fossils have been determined by Dr. Dall as Pliocene to recent. As the beds lie unconformably under Quaternary alluvium, they are probably Pliocene or early Quaternary in age.

### LAKE BEDS NEAR HAIWEE

Toward the south end of Owens Valley, in the vicinity of Haiwee post-office, there is a series of calcareous and arenaceous lake beds. They were seen by the writer ½ mile southwest, 1 mile east, and ¾ mile northwest of the post-office. They are fine, white, and distinctly bedded. East of the post-office, the beds dip 8° to the northwest. Northwest of the post-office they dip 14° north. They were best seen ¾ mile northwest of the post-office, where a hill 175 ft. exposes them from top to bottom. They consist of light-colored, siliceous fine clays or shales. In the lower part of the exposure numerous small flat bodies of gypsum occur. Most of the plates lie parallel with the beds, but in some places they appear as secondary bodies along joints and faults.

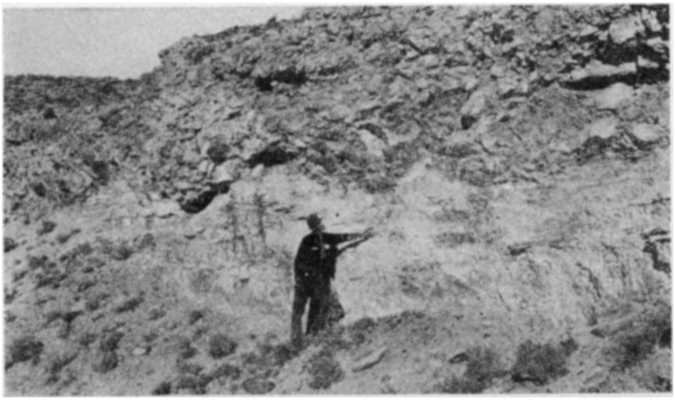

FIG. 16.—Unconformity between Quaternary conglomerates and Pliocene lake beds north of Haiwee. Some of the bowlders of the conglomerate are composed of the underlying clays.

The lake beds here are covered with a hard, coarse conglomerate derived from the Coso Mountains to the east. The lake beds and conglomerates are unconformable. The conglomerate lies on the very irregular surface of the truncated edges of the dipping beds of clay, the surface between the two having a relief of about 15 ft. (Fig. 16). The constituents of the conglomerate are chiefly granite, sedimentary rock, and scoriaceous basalt, but near the contact many large fragments of the underlying clays are also included. The conglomerates must be as old as the early Quaternary. The hill on which they occur is far from the Coso Mountains and separated from them by numerous valleys, similar hills, and more lake beds. The lake beds are then pre-Quaternary, probably Pliocene, and correlated with the similar beds in Waucobi Canyon. No fossils were found here.

### OLDER DEPOSITS AT THE FOOT OF THE INYO MOUNTAINS

Bearing in mind the main characteristics of the deposits described above, and accepting the idea of their lacustrine origin, as we are apparently forced to do, we can proceed to a description and interpretation of the older deposits of terrestrial material at disconnected points along the foot of the Inyo Mountains.

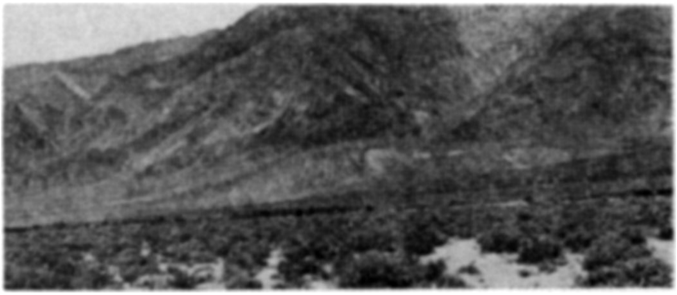

FIG. 17.—Low hills of old deposits surrounded by present-day fans, northeast of Mt. Whitney station.

*Distribution as indication of age.*—At several places, most notably northeast of Mt. Whitney station and east of Citrus, hills of terrestrial material rise 100 ft. above fans which are now in process of making about them. The materials of the hills differ from those of the fans in texture, and in the fact that they are cemented.

Along the west face of the mountains immediately northeast of Mt. Whitney station, an exceptional series of events is recorded by the nature and relations of the alluvial deposits. Two hills, 100 ft. or more in height, occur half a mile apart, and half a mile from the foot of the mountains. Between and around these hills the lower surface is covered with the typical alluvium of the region. The hills themselves are of gravel and sand. Evidently a great deposit was laid down here, its remnants being represented by the hills. Conditions changed so that erosion took place, the old deposit being dissected into hills and valleys. Later, as the streams were brought to adjustment again, they deposited new fans among the remnants of the old deposit (Fig. 17).

Due east of Citrus, a series of low spurs projects from the foot of the mountains into Owens Valley. At the foot of the mountains they stand 50–75 ft. above the plain, and become gradually lower westward. They are not in direct contact with the present fans, though fans occur at lower levels north and south of them. These projections are not at the mouths of present canyons (Figs. 18 and 19).

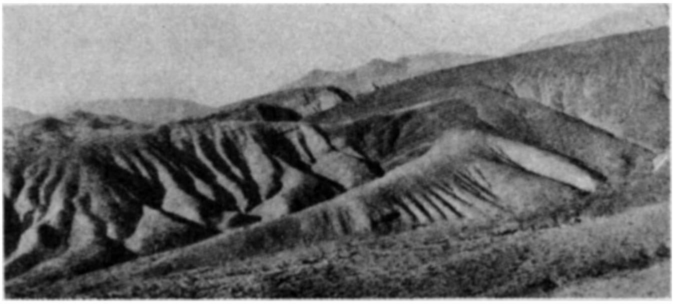

Fig. 18.—Lacustrine beds (light colored) lying against rocks of the Inyo Mountains (darker rock to the right), east of Citrus. Stratification may be seen in the left center.

The deposits in Mazourka Canyon, the canyon east of Aberdeen, and on the flanks of the mountains east of Keeler should also be included in this category. In the two canyons, older cemented gravels occur as distinct, flat-topped, but eroded terraces, 50 ft. above the stream beds. East of Keeler, hills of conglomerate rise 200 ft. above present alluvial surfaces.

*Constitution.*—The materials of the older deposit at the foot of the Inyos differ from those of the Sierra bajada in various ways; especially in (1) lithological composition, (2) texture and shape of pieces, (3) structure, (4) cementation.

1. This deposit is made up of fragments of all rocks occurring in the Inyo Mountains, from which they are derived, including both igneous and sedimentary rocks.

2. The constituents have not a great range in size. In place of large bowlders, the coarser materials are large-sized cobbles or very small bowlders. Texturally, the fine material is sand or clay. The average size of particles is probably less than half an inch in diameter. Bowlders even as large as 1 ft. in diameter are wanting.

In the Sierra bajada the pieces of rock are either ice-shaped, or they are almost as angular as when broken off by weathering. Here the effects of glaciation are not seen. The fragments have been worn to pebbles, few sharp or irregular edges appearing. They are in general well rounded, having been shaped by the action of water.

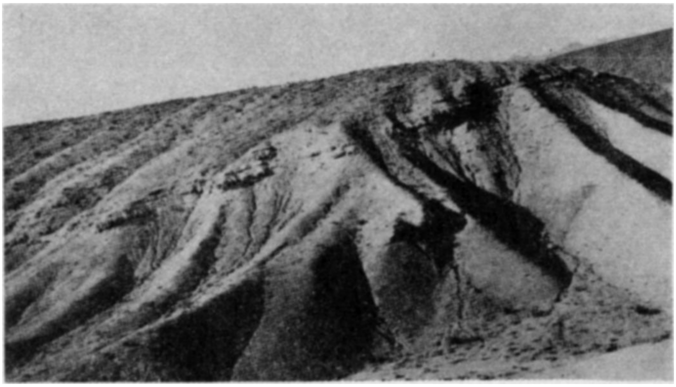

FIG. 19.—Close view of the older deposits east of Citrus. Note the layered structure and the dip of the beds.

3. These materials are arranged in definite, continuous layers of gravel and sand. The layers can be traced the whole length of the various outcrops as beds of nearly uniform thickness. East of Citrus a definite, continuous layer of clean, fine gravel, uniformly 2 ft. thick, overlies a layer which is a mixture of small angular fragments, sand, and clay. Northeast of Mt. Whitney station the talus from a deep cut is of uniform-sized cobbles and sand. The stratification of this material may be seen in Figs. 18 and 19.

Wherever exposures were seen east of Citrus, the beds have an appreciable westward dip (away from the mountains). Clinometer readings vary between 8° and 18°. The *direction* of dip is nearly constant. No faults, minor folds, or other evidences of diastrophism were seen. This dip may be depositional, or the beds may have been tilted to their present position by an uplift in the mountains. Eighteen degrees is a high dip to be considered depositional when the material is fine.

4. The older deposit shows a tendency toward cementation, and some layers are firmly cemented. In general it is the layers of coarse material, originally more porous, that are cemented.

In the beds east of Citrus mentioned under (3) above, the upper layer of gravel is cemented to firm conglomerate. It is so solid as to ring under the hammer and to need more than one hard stroke before it is broken. The material of the finer layer below cannot be picked out by the hand, but yields readily to the hammer. The gravel layers are almost everywhere so indurated that they stand out conspicuously, the determination of dips thus being made easy.

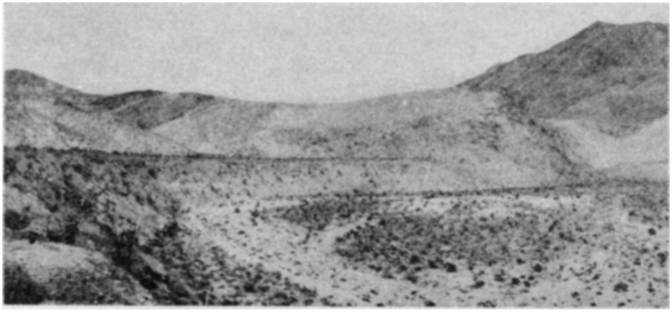

FIG. 20.—A stream terrace of older alluvium in Mazourka Canyon

The above characteristics hold for all the deposits of older materials at the foot of the mountains, with the exception of those in Mazourka Canyon. The deposits in this canyon belong to the older deposit, for they occur in terraces above the present depositional surfaces, but the materials are in some respects different. Areally considered they take the form of the canyon in which they were deposited, and thus occur in a long strip. They constitute more or less definite stream terraces on the sides of the present valley (Fig. 20). Texturally they are like the deposits along the foot of the mountains, the chief difference being in the stratification. Instead of being in definite layers, as are the deposits at the foot of the mountains, the materials in the canyon are in indefinite lenses and pockets, similar to those of the Sierra bajada, though on a much smaller scale.

An examination of two detailed sections noted just above Barrell Springs brings out the difference between these deposits and those east of Citrus and Mt. Whitney station:

1.

| | |
|---|---|
| 1½ ft. | Angular fragments the size of cobble, and clay. |
| 1 ft. | Well-sorted, very fine gravel. Pinches out in both directions. |
| 1½ ft. | Mixture of cobbles and clay. Pinches out upstream. |
| 1½ ft. | Clay with some small angular bits of rock. |
| 1 ft. | Well-sorted, loose, fairly well-rounded cobbles; average size 1½ in.; one-inch clay layer in middle. |
| 3 ft. | Mixture of sand, clay, and gravel; little or no stratification; pockety; contains one bowlder one foot in diameter. |
| 2½ ft. | Clay, sand, some gravel; poorly sorted. |
| 2½ ft. | Fine angular fragments; little or no clay or sand; well assorted. |

2. Fifty feet down the valley from the last, the following section occurs:

| | |
|---|---|
| 3 ft. | Mixture of coarse and fine angular gravel, with clay in the interstices; average size of constituents 1 in. in diameter; occasional bowlders 1 ft. in diameter. |
| 1 ft. | Moderately fine gravel; little or no clay; no pieces larger than 3 in. in diameter; pinches out in 12 ft. up valley. |
| 2 ft. | Clay and pebbles intermixed; rude layer of cobbles in middle. |
| 2½ ft. | Fairly well-sorted gravel, coarser at bottom. Pinches out rapidly in both directions. Loosely packed, interstices not filled. |
| 3 ft. | Irregularly bedded bowlders, cobbles, fine gravel, clay. |
| 2 ft. | Indefinitely bedded fine angular gravel. Average ½ in. in diameter. |
| 1 ft. | Pockety, coarse gravel, constituents up to 10 in. in diameter. |

In both sections, the materials are slightly cemented. Not a single subdivision of one could be traced 50 ft. to the other. For further details of these materials see Figs. 21 and 22.

It is thus seen that the materials of Mazourka Canyon differ from the rest of the older deposit at the foot of the mountains in that it includes coarser materials and has a lens and pocket structure (cf. Figs. 19 and 21).

*Origin of the older deposit at the foot of the Inyos.*—It will be seen from the foregoing that most of the older deposit is sufficiently unlike the Sierra bajada to lead one to conclude that its mode or conditions of origin were not the same. On the other hand, if it be compared with the near-shore phase of the lake beds in Waucobi Canyon, a strong resemblance will be seen: (1) Both deposits were formed and eroded before the deposition of the recent alluvium. (2) Both are firmly cemented, at least locally. (3) They are similar in texture, both being fine and having a low textural range. (4) Their stratification is the same, both being sorted into layers. They are dissimilar in that the constituents of the deposits at the foot of the mountains are better rounded than those in Waucobi Canyon, and the former contain no fossils. With such similarities between these deposits and the lake beds, it seems clear that the older materials northeast of Mt. Whitney station and east of Citrus are of lacustrine origin, and belong to the same formation as the lake beds in Waucobi Canyon and at Haiwee. If so, the lake in which they were deposited was shallow, and the shore lay against the

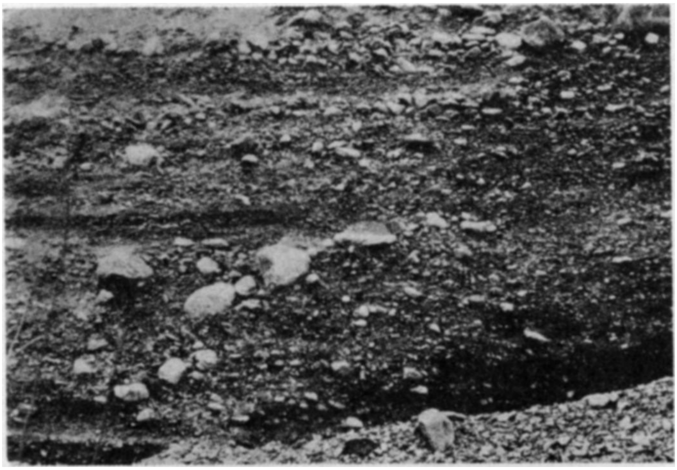

FIG. 21.—Stream deposit in Mazourka Canyon. Compare with Figs. 14 and 15

mountains immediately to the east. The dissection of the deposit probably took place subsequent to the uplift of the mountains and the draining of the lake. If lacustrine beds corresponding to them were deposited at the foot of the Sierras, they have been covered and concealed by the more recent alluvium.

The deposits in Mazourka Canyon are obviously not lacustrine, but of stream origin. They were probably laid down on the floor of a mature valley, which was tributary to the lake east of Citrus.

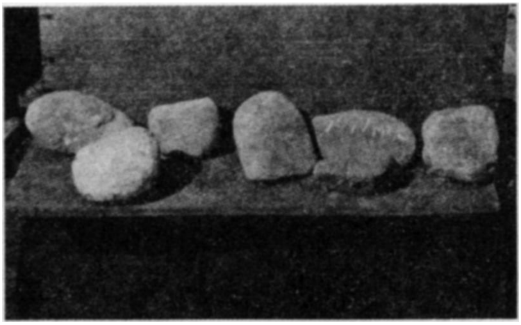

FIG. 22.—Photograph to show the shapes of the cobble in the terrace of Mazourka Canyon.

The differences between these deposits and those along the foot of the mountains may be taken as differences characteristic of lacustrine and fluvial deposits.

## THE PRESENT FANS

### DISTRIBUTION

Between Mt. Whitney station and Aberdeen there are nine separate fans at the foot of the Inyo Mountains. On the map (Plate I) they are numbered 1 to 9, beginning at the south. Of the nine fans, 1, 2, 4, and 8 are large, each covering more than a square mile, and 3, 5, 6, and 9 are smaller. All of them occur at the mouths of mountain canyons. The largest one, No. 4, is at the mouth of the largest canyon, Mazourka, though it is not so well shaped as the others. Between the mouths of the main canyons and between the main fans are some patches of alluvium too small to map and not important in any way. These patches occur at the lower ends of very small valleys. Fans also occur along the mountains outside the mapped area. They were seen northeast of Aberdeen and at Keeler.

### SHAPE AND TOPOGRAPHY

In general there are two controlling factors in the shapes of the fans. At their mountainward edges they are confined by the walls of the mouths of the canyons, from which they take their form. Their outer edges deploy slightly on the plain. Nos. 2 and 8 extend about a mile into their canyons, and No. 4 extends still farther up Mazourka Canyon. Nos. 1 and 3 show deployment on the plain. No. 2 is made up of two smaller fans, with a depression at their junction.

The surfaces of these fans are very similar to the surface of the Sierra bajada, except that all features are on a smaller scale, the fans, except No. 2, are simpler and remain separate, and these fans are not now in process of dissection. The individual fans show numerous radiating channels and low ridges similar to those on the Sierra plain, but they give the surface here a relief of no more than 7 or 8 ft. at a maximum. The ridges are almost invariably belts of bowlders. The fans are not dissected as is the Sierra bajada. The streams still flow on the surface in the radiating channels, but they flow only after the infrequent rains in the mountains.

The slope of the fans varies considerably from head to outer edge. Fan No. 8 has a slope of about 10° at its head, 5–6° midway of its length east and west, and approaches flatness at its outer edge. Fan No. 1 has a slope of more than 600 ft. per mile in its upper part. The upper part of fan No. 2 slopes westward 800 ft. in a mile. This is steeper than the average.

### MATERIALS

These fans at the foot of the Inyo Mountains have not been dissected, and exposures of the material are therefore few and shallow. Some data can be collected from surface materials, there are a few shallow cuts along the channels, and one prospect pit affords a good exposure.

Each fan is made up of pieces of the kind of rock in which the canyon back of it is cut. For instance, 99 per cent of the material of fan No. 8 is granite, the other 1 per cent scoriaceous lava and slate. All the face of the mountains here is granite, which is bordered along the edge of the Santa Anita flat by slate. Lee[1] maps a volcanic mountain southeast of Aberdeen, which doubtless explains the occasional fragments of scoriae. The fan northeast of Aberdeen is composed of bits of granite, gneiss, scoriaceous basalt, and limestone. All these rocks occur together in the walls of the canyon. Fan No. 1 is made up largely of bits of lava, sedimentary rock, and granite. No. 2 is mostly of sedimentary rock and lava, with some fragments of granite. No. 3 contains a mixture of sedimentary rock, diorite, and granite, in keeping with the rocks east of it.

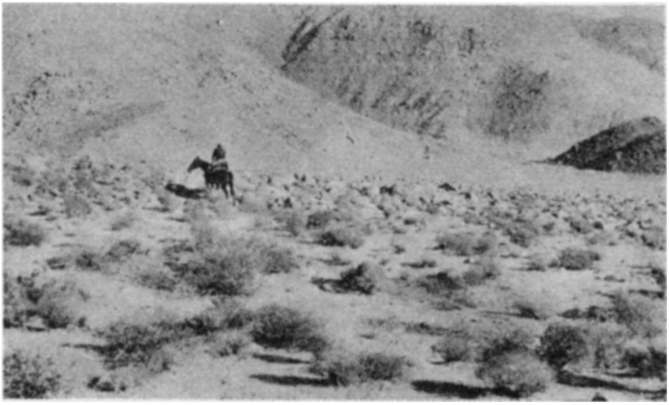

FIG. 23.—Bowlders on the surface of fan No. 8 north of Citrus. Their size may be estimated.

On the surface of the fans there are both coarse and fine materials arranged as on the Sierra bajada in diverging lines or belts from the head of the fan.

Though the bowlders are not so large as on the opposite side of the valley, they are still astonishingly large for the drainage by which they were transported. The largest bowlders seen were near the head of fan No. 8, where there are some 10–12 ft. in diameter. On fan No. 2 bowlders are especially numerous. Toward the head of the main fan the entire surface is so covered with them that a horse cannot travel over it. The average size of the bowlders is about 1½ ft. Their number and size can be seen in Fig. 23. The photograph was taken from fan No. 8.

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[1] W. T. Lee, *Water Supply and Irrigation Paper, U.S. Geol. Surv., No. 181*, Pl. I.

These bowlders show little shaping. If fragments were broken from ledges by the wedge work of ice and gravity, and then the sharp and irregular edges dulled during a short period of transportation, their present shape would result.. Neither glaciation nor prolonged rolling has affected them.

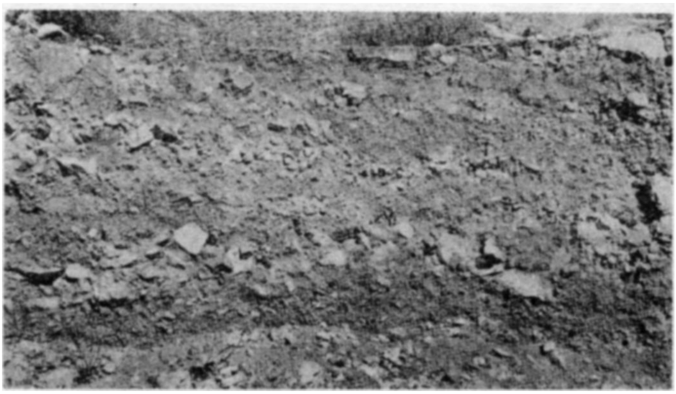

FIG. 24.—Angular material in the fans at the foot of the Inyo Mountains

The fine material on the surface of the fans occurs in largest areas near the outer edges, where there are few bowlders, and the surface material has about the texture of fine gravel or coarse sand. A half-mile from the edge it is made of fragments more or less shaped by transportation, averaging perhaps 3 in. through, with some lines of larger bowlders. At the head the surface is practically covered with bowlders.

Although exposures of material beneath the surface are almost wanting, a few shallow cuts were seen. The data they afford follow:

1. In the outer edge of fan No. 8, 4 miles south of Aberdeen, is a pit dug as a placer prospect, 10 ft. deep, 15 ft. long, and 5 ft. wide. The material is all fine, there being nothing as large

as 1 in. in diameter. The pieces are distinctly angular. The section follows:

3 ft......Fine clay and gravel, not laminated.
1 ft......clay
2 ft......fine gravel
½ in......clay
3 ft......fine gravel
2 in......clay

2. Ten feet of material are exposed in the fan northeast of Aberdeen. It is not stratified. Angular bowlders are imbedded in a matrix of clay.

3. Near the upper end of fan No. 2, a gully affords an exposure. The section consists of both stratified and unstratified material. In the unstratified parts, the main constituent is clay, in which are imbedded numerous angular bowlders. One 3½ ft. in diameter occurs in a mass of clay.

4. Distinctly angular alluvium is shown in Fig. 24.

### SUMMARY

It is apparent from the foregoing that there are two sorts of terrestrial deposits in and at the foot of the Inyo Mountains, of two distinct ages. The first deposits appear to have been made when the mountains were low and bordered by a lake. Mazourka Canyon had been cut and brought to grade, deposition taking place in its bottom from its mouth up. The deposits of the time are all fine, fairly well sorted in Mazourka Canyon, and very well sorted in Waucobi Canyon and along the mountain foot.

Conditions so changed that these first deposits were largely removed by erosion. The change was probably brought about by the uplift of the mountains, as the later alluvium is much coarser than the older. After the uplift, new canyons were cut in the mountains, and new fans deposited among the remnants of the old lacustrine deposits. This process is still going on.

## SOME PROBLEMS OF THE TERRESTRIAL DEPOSITS

The fluvial deposits of Owens Valley, as described above, offer several problems. In some cases the solutions of the problems are simple and obviously correct; in others the solution is not so clear, and there is some doubt as to the correctness of tentative conclusions; in still other cases, the solution is entirely hypothetical. In some cases various lines of explanations may have partial application to the observed features. These problems are here discussed individually.

## MANNER OF FORMATION OF THE FANS AND BAJADA

### CAUSES OF DEPOSITION

Material was deposited at the foot of the Sierra and Inyo mountains, primarily because of an abrupt decrease in the gradient of the streams. When the mountains were first uplifted, and precipitation fell on the slopes, streams formed and flowed swiftly down the sides, carrying material from their channels. When the base of the mountains was reached, the carrying power was suddenly and greatly decreased, and the first deposition resulted.

Once started, other factors tended to increase the process of deposition. Streams lost volume by sinking into loose material. This not only reduced the volume of the transporting agent, but also lessened the velocity of the water remaining at the surface; both these changes caused deposition.

The average relative humidity of the Sierra Nevada Mountains is not far from 60 per cent, and that of Owens Valley probably not more than 40 per cent.[1] When the streams reach the plain, evaporation is increased; hence loss of volume, loss of velocity, and decrease in carrying power. This would not be so important in the case of the Inyo Mountains, because the difference in humidity between mountains and plains is not so great there. However what little rain falls, is in the mountains rather than on the plains, and evaporation takes place more rapidly in the latter locality.

Water taken from streams by irrigation so decreases their volume in some other localities as to aid in causing deposition, but such is not the case in this region. The Sierra bajada has been undergoing dissection rather than gaining by deposition since man began to irrigate the lands, and the streams on the Inyo fans, running only after rains, are not used for irrigating purposes.

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[1] For details of precipitation and evaporation in the valley, see *Water Supply and Irrigation Paper, U.S. Geol. Surv., No. 181*, pp. 17–25.

Decrease in volume and consequent decrease in velocity took place on the plains for another reason also. It rained heavily or snow melted rapidly in the mountains, and the mountain streams acquired great volume and velocity. When the rain ceased, or the temperature dropped below 32°, the flood on the plains subsided from lack of supply from above. This undoubtedly furnished conditions under which a large proportion of the material of the fans was deposited.

Glaciation has played a large part in the deposition of the Sierra bajada. Glaciers prepared immense amounts of material in the mountain canyons for transportation by streams. At the same time they furnished great volumes of water to act as the transporting agent during the melting-season. The initial volume and the load being at a maximum, deposition took place on the plains at an unusually rapid rate and to an unusually great extent.

### FORMS TAKEN BY THE DEPOSITS

Deposition necessarily took place at the foot of the mountains, at the end of the mountain canyons. The streams flowed on down over the deposit it had made, until it disappeared; hence the fans slope away from the mountains. While the stream was depositing and especially at times when floods were subsiding, channels were filled, distribution took place, new channels were made and filled, and water courses changed constantly. In each new distribution the channels diverged from the mountains. The resulting feature is broader near its edge than near the head; that is, it is roughly fan shaped.

In the Inyo Mountains there is little precipitation, the canyons are far apart and small, and the fans are accordingly too far apart and have grown laterally too short a distance to have been joined. The result is a series of separate fans. In the Sierras, the streams issue at sufficiently small intervals and have built fans of sufficient size, so that they have coalesced to make a compound fan, piedmont alluvial plain, or bajada.

When fans first join, the compound fan is a series of fans, with low places between. If Oak Creek, Shepard Creek, and Hogback Creek are considered as types, there is a tendency for streams to leave their fans and locate their main channels in the inter-fan depressions. Deposition then takes place in the depression, building it up and making a fan across the edges of two earlier fans. Presumably streams will shift back to their original positions when those positions have become lower than the site of the original depressions, through deposition in the latter. Streams then shift from fans to depressions, make fans there, shift back, build up the old fans, shift again, etc. How frequent and important this may be is not clear. If streams shift freely from higher places to depressions, it is surprising that fans of the bajada stand 200 ft. above the low places between them. The general relief of the bajada should be very slight. The water forming depositing streams probably does not adjust itself freely to the low places, though it is clear that it does so in many cases. The origin of the diverging channels is clear.

## THE TRANSPORTATION OF LARGE BOWLDERS

One could hardly travel a mile on the Sierra bajada, or see the heads of the fans at the foot of the Inyo Mountains without asking how the large bowlders came to their present positions. It is essentially a problem of the means of transportation of the largest bowlders farthest from the mountains, for if they can be explained, the smaller bowlders may be considered to have been carried shorter distances by the same methods. Probably the most difficult problems are offered by the largest bowlders, such as those west of Lone Pine, 6 miles from the mountains, measuring 10×20×30 ft. above ground, and the one at the Cerro Gordo power shanty, larger than the one first mentioned and 1½ miles from the mountains, and several others in that vicinity about as large.

It is clear that these bowlders came to their present positions through the agency of water. Though their size suggests glaciers as the transporting agents, such an explanation is out of the question. The lower limit of glaciation is distinctly marked in the mountain canyons above. The glaciers did not descend to the plains. Nor is there anything in the fact of icebergs floating in a lake. The deposits with which the bowlders are associated are not lacustrine, and no lake existed in the valley during glacial times. The surface on which the bowlders lie clearly was made by running water. The bowlders are so clearly a part of the fans, and the fans are so clearly running-water deposits, that the bowlders must be considered to have been transported by running water.

It is also clear that the bowlders were not transported according to the common and well-known methods of stream transportation. They have certainly not been rolled along the bottoms of streams in the usual way. They have not the rounded form characteristic of such motion. On the surface of the fans, furthermore, it is impossible for streams to have existed deep enough and strong enough to have so rolled these bowlders. Such streams would have to have a depth about equal to the diameter of the bowlders, be confined in a narrow channel, and flow with a velocity almost inconceivable for a stream. As the bowlders occur on the higher parts of the fans, water of sufficient depth to have carried them would have formed a sheet 20 ft. deep over the fans, and 220 ft. deep over the inter-fan depressions. Even then it would not have been confined to a narrow channel. Also the gradient of the fans is relatively low. Where the largest bowlders are, the slope is not over 6°, and west of Lone Pine not more than 3°. Bowlders much smaller than these are not now being rolled down the mountain canyons above, where the streams are sharply confined and the gradient is very high. The volume of the stream may have been sufficient to carry them *in the canyons* when the glaciers were there. The problem involves transportation *on the fans only*. They were perhaps carried to the heads of the fans by glaciers, glacial waters, and gravity. From there to their present positions, some special methods are called for.

A clue to a possible manner of transportation for these bowlders is obtained from observations of run-off water at the side of a previously dusty road after a heavy rain. Where the running water is but a small fraction of an inch deep, pieces of rock an inch in diameter are carried down stream. The moving of the large pieces involves the transportation of a very much greater amount of fine material. The movement of the large pieces is accomplished by the removal of fine material from the area immediately down stream from, and under, the lower part of the large piece. By undercutting in front, and then by gravity and the push of water and sediment from behind, the large piece is pulled and pushed forward into the depression prepared for it. This process takes place over and over again, the large piece being moved down the low gradient in a halting fashion. The depth of the depression into which the piece falls is never so deep as the diameter of the fragment moved. Once started in motion, the piece is sometimes carried many times its own length by its momentum, and by the force of water and gravity. The motion is usually one of sliding rather than rolling.

It is conceivable that these same methods might operate on the surface of an alluvial fan, on a scale large enough to transport bowlders even 20 ft. in diameter distances of several miles. The bowlder starts from the head of the fan in company with a relatively large amount of fine material. The volume of the stream varies greatly from time to time, with great differences in precipitation in the mountains, and with daily and seasonal ranges in the rate of melting of glaciers. Material is deposited and rehandled time and time again. When the volume is great, fine material is removed from the front of the bowlder and from beneath its front edge, while other material is piled against its upper side, and the bowlder falls, or is pushed, or rolled over into the depression. As the flood subsides, the bowlder may be almost or completely buried, but the next flood uncovers it, and the process is completed. With sufficient time, sufficient variation in volume of water, and sufficient rehandling of material, huge bowlders may thus be transported great distances.

Would the slope of the fans be sufficient for such transportation? In the roadside rill the piece of rock moves a distance several times its own length, while dropping less than its own diameter. Suppose the bowlder 20 ft. in diameter moves 40 ft. horizontally, with a fall of 15 ft.; this would require a gradient of 1,980 ft. per mile. If it moves 60 ft., with a 10-foot drop, the gradient would be 880 ft. per mile. The average slope of the bajada is about 400 ft. per mile. This requires that the bowlder west of Lone Pine, 10×20×30 ft., move about 120 ft., or four times its own length, in dropping 10 ft., or about its own smallest diameter, if the proportions observed hold.

This is conceived to be possible. The process is greatly aided by the momentum obtained by the bowlder when it first moves toward the depression. The depression below the bowlder would not be deep, before the crowding of the material above, and the force of water and gravity would force the bowlder into it. The depression would play out very gradually down slope, giving a constant gradient down which the bowlder could roll, slide, or creep.

Obviously this process would operate to best advantage where there was the greatest volume of water, and where fluctuations of water were greatest; that is, along the main channels of the fans, and on the Sierra fans rather than at the foot of the Inyo Mountains. Bowlders are usually arranged in lines related to the channels, and they are more abundant and larger on the Sierra bajada than at the foot of the Inyos. If this method of transportation of large bowlders is not adequate, methods which are, are not known.

### LENS AND POCKET STRATIFICATION

It was shown above (pp. 717–22 and 735–37) that the materials of the fans of the region are but crudely sorted, and that the different textural grades take the forms of lenses and pockets, rather than definite and continuous layers. No textural division was traceable more than 50 ft. in any cut, before it played out in one direction or another. The explanation of this seems clear.

On the surfaces of all the fans in the region are numerous radiating channels and low ridges. In Mazourka Canyon, these channels are braided in almost all directions, though along lines trending generally down valley. These surfaces represent the last deposition on the respective fans. Beneath the present surface there must be many similar surfaces, made and buried as the fan was built.

When flood waters flow over a fan, radiating channels are formed. As the flood subsides, or if the waters are overloaded otherwise, deposition takes place in the channels. The channels are filled with whatever grade of material the stream finds itself unable to carry, and the stream is forced over the side. It then makes a new channel, fills it, and overflows to repeat the process. The fan grows by the addition of long narrow strips of material, sorted roughly into different textural divisions. These strips diverge from the axis of the fan.

No straight section can be cut in such a deposit without cutting the filled channels. If the cut is longitudinal, practically all the channels will be cut obliquely and at low angles; a few might be cut at right angles. If the fan is dissected by streams cutting down in the old channels, buried channels will still be cut obliquely, as distribution does not take place along lines exactly parallel with previous distributaries.

The filling of a buried channel, when cut along a straight line oblique to the original channel, is exposed as a lens whose length and degree of pinching out depends primarily on the obliquity of the line of cut. A channel filled, buried, and then cut at right angles reveals itself as a pocket in section, the size and shape of which depends on the size and shape of the channel. Continuous layers, uniformly thick can occur only where the depositing distributary was long, straight, and contained uniform material, and where the filling was cut along a straight line exactly parallel to itself. Obviously where exposures are along longitudinal cuts, the result is many lenses, a few pockets, and practically no continuous layers.

That this is the correct explanation of the lenses and pockets of the fans of the region is shown by a correspondence in size between lenses and present surficial channels. On the Sierra bajada, the channels are about 8–10 ft. deep on the average, and the lenses and pockets are about 8–10 ft. thick at their thickest parts. The present flood surface in Mazourka Canyon has a relief of about a foot; the lenses in the older alluvium near by have just about that thickness.

It is understood that any deposit from distributing or anastamosing streams will reveal a lens or pocket structure in straight cuts. The principle probably applies to all alluvial fans, piedmont alluvial plains, flood-plain deposits, glacial valley trains and outwash plains, and deposits on tidal deltas.

## THE DISSECTION OF THE SIERRA BAJADA

A variety of events might bear causal relations to the dissection of alluvial fans. Among them are changes in climate, uplift of the fans, down-warping of their surroundings, etc. Such events and resulting processes may be complex. The cause of dissection in this case, however, seems to be the cessation of glaciation, and the process seems simple.

All the material seen in the bajada, even to the bottoms of the canyons, shows evidence of glacial wear. Before the mountain canyons were glaciated, the fans must have been smaller and lower than now by an amount at least equal to the depths of the canyons. Glaciers were formed, which carved great amounts of material from the heads of the canyons, carried it to their lower ends, and, melting, supplied great quantities of dêbris-laden waters to flow out over the fan. The fans grew rapidly and became large, out of all proportion to those at the foot of the Inyo Mountains, which were not affected by glaciers.

When the glaciers in the mountains had melted away, these enlarged fans were dissected, for the same reason that a valley train is trenched. The streams now reach the fans with less material than they carried when the glaciers existed, and are able to erode material from the fan.

The matter may be looked at in another way. The pre-glacial fans, being lower than the present ones, had lower gradients and made a sharper break in gradient at the foot of the mountains, and deposition progressed. Now that the fans are higher, their gradients are steeper, and the break in gradient at the foot of the mountains is not so great, and the streams flow out over the fans with their velocities less checked than formerly. This means at least that there will be less deposition on the present fans, and, taken with the fact that the streams have less load, plays a part in the erosion of the fans.

Presumably the canyons will be deepened almost or quite to the bottom of the glacial material. This depth has nowhere been reached as yet.

## DEPOSITS OF TWO AGES AT THE FOOT OF THE INYO MOUNTAINS

The older deposit at the foot of the Inyo Mountains is here considered to be a lacustrine deposit, coinciding in age with the lake beds in Waucobi Canyon and those near Haiwee. If this be correct, the explanation of the dissection of these deposits and the later deposition of fans is not complex.

A lake existed in Owens Valley, probably in Pliocene times, and deposits were laid down in it on the flanks of the mountains. The lake was drained or dried up, and the mountains were probably uplifted. Dissection of the deposits thus exposed and uplifted followed. After erosion had removed a large part of the lacustrine deposit, deposition began at the foot of the mountains, and the present fans have been built up among the remnants of the old lacustrine deposits.

## CRITERIA FOR DISTINGUISHING ALLUVIAL FAN MATERIALS

In conclusion we may bring together the distinguishing features of the materials of fans, as seen in this region. The region affords especially good facilities for the drawing of such conclusions, as it contains both running-water and standing-water deposits of similar ages.

Deposits on alluvial fans may be distinguished from those in still water, either lacustrine or marine, as follows:

1. In alluvial fans, coarse material has a wide distribution as against confinement to a narrow zone near shore in standing-water deposits.
2. Textural range in single exposures is large in fan materials.
3. Fan materials are not in general so well sorted as deposits in standing water.
4. The beds and surfaces of fans are likely to have slopes of 6–18°, as against 0–3° in standing-water deposits.
5. Fan materials are likely to have fewer and different fossils than deposits in standing water.
6. Fan material has a lens and pocket stratification, as against a sorting into more or less uniformly thick horizontal layers, as in lakes or seas.
7. Huge bowlders widely distributed vertically and horizontally in a deposit indicate that it was deposited by running water, and with a large proportion of fine material; that is, they indicate that the material is part of an alluvial fan deposit, except in cases where glaciers have affected it, or where standing waters could have

received icebergs, or where basal conglomerates are formed near shore.

8. Theoretically, fan material will be more compact *at first* than still-water deposits of the same textural grade, as each particle drops to the bottom with greater force and the film of water around each particle is not so thick. After water is drained from both deposits, still-water deposits are likely to be more cracked than fan materials, because they contract more. After cementation, still-water deposits, say of clay, will have more veinlets than fan materials of the same texture.